Effects of Langmuir Circulations on the Plankton

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LONG-TERM GOAL

My long term goal is to contribute to our understanding and prediction of the dynamics of marine populations and ocean-atmosphere interactions. Of particular interest to me are the effects of weather, and its climatic variation and long-term change, on the plankton and fish.

OBJECTIVES

My object remains the same as that stated last year. I wish to establish whether the plankton is affected by Langmuir Circulations (LCs). LCs are wind- and wave-induced flows in the mixed layer (ML) and comprised of counter-rotating, helical cells aligned with the wind. They occur widely and frequently. While their surface manifestation is relatively well known, their dynamics and relation to the plankton are less well understood. Of particular interest is the effect of flow on plankton distributions and associated processes, including feeding. The challenge is to measure plankton distributions and processes simultaneous with the physical flow and property distributions.

Specific, and final, objectives of my work remain to (a) verify pattern of zooplankton-sized particles, observed with the profiling Optical Plankton Counter (OPC), by comparing them with results of the simultaneous sampling of the plankton by use of a pump, and (b) investigate the relation of the observed distribution of scalars (temperature, chlorophyll *a*, and zooplankton) to turbulence, heat flux, and other scalars and vectors.

APPROACH

I participated in the second FLIP cruise of the ONR Marine Boundary Layer (MBL) program, approximately 60 miles off Monterey, with marine meteorologists and physical oceanographers. My general approach was to sample the plankton and its environment continuously in the vertical, by profiling between the top and base of the ML with a cycle time about 1-3 minutes, and at a single depth within the ML, at higher frequency. Measurements were made of temperature, salinity, and sigma-*t* (CTD), flow (Acoustic Doppler Velocimeter, ADV), chlorophyll *a* concentration (Chlorophyll Absorption Meter, CHLAM), and zooplankton concentration (plankton pump collections; Optical Plankton Counter, OPC).

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WORK COMPLETED

My annual report last year summarized progress to that date, to which I have added as follows. First, our cruise was a success in regard to samples and data obtained and the range of forcing (wind, waves) experienced. Second, nearly all data have been processed to an error-free level, with certain periods having been examined in detail. Third, all plankton samples have been analyzed (individuals enumerated). Fourth, all data have been merged into files amenable for further analysis, particularly of pattern. Finally, analysis continues of the ADV and CTD data, from selected periods, for the investigation of turbulence and and heat flux.

RESULTS

As stated last year, LCs occurred and were quantified by our measurements. Conditions progressed from benign, with a stratified upper ocean, to strong winds and high waves, with well-developed LCs, followed by abatement. Forcing was quantified by estimating LC convergent velocity. LCs were manifest in the temperature distribution of our profiler data. In particular, in the time-depth domain, sections within LCs showed cool water entrained upward from the base of the mixed layer to the surface. These patterns persisted on the scale of hours. Temperature at a single depth within well-developed LCs varied in a semi-periodic fashion over a range of the order 0.02 deg C. Such measurements enable us to construct a physical context in which to interpret our biological observations.

Our OPC data show pattern in the time-depth domain in both stratified (initial) and LC (mid- to late-term) conditions within the experiment. Pattern in stratified conditions showed variation in the vertical and layers in the horizontal. Pattern in LCs showed patchiness in the mixed layer, in both the horizontal and vertical. The challenge, which we continue to address, is to determine whether such pattern is real or artifact. While I believe it is real, independent verification is needed. Such comes from the pump-collected and microscopically-counted zooplankton (see below). Work continues on this question. Other potential sources of data for comparison and potential verification include video of the pumped flow (Checkley) and acoustic backscatter (Pinkel).

Also, as discussed briefly last year, our desired method of estimating turbulence using our 25-Hz ADV measurements of velocity at a fixed depth within the mixed layer appear subject to artifact. As an alternative, we are now considering the analysis of turbulence by analysis of temperature inversions and estimation of the Thorpe scale. This method is not without problems and hence we remain skeptical of its efficacy in our case.

We have compared zooplankton concentration, inferred from microscopic analysis of our pump samples, with the concentration of zooplankton-sized particles, inferred from OPC data. In those cases where the range of variation of zooplankton concentration was large (e.g. 2-10 particles/liter), correlation is high and significant. In those cases where the range of variation is low (e.g. 8-12 particles/liter), the correlation is low or non-significant. Examples of the former are depth-dependent variation in zooplankton abundance in a stratified water column (e.g. 0-30 m early in our experiment). Examples of the latter are time- and depth-dependent variation of zooplankton abundance in the mixed layer in LCs.

Characterization and analysis of pattern in temperature, chlorophyll *a* concentration, and, particularly, zooplankton concentration continues. We use the Lomb periodogram for all scalars and Lloyd's index of mean crowding for the zooplankton data. We have also begun to use geostatistics, particularly variograms, to this end, in collaboration with a colleague, Dr. Nicolas Bez, from the Ecole des Mines (Paris, France).

Finally, we wish finally to synthesize our data with those of other investigators in this experiment. These include data on acoustics (Pinkel), nutrients (Dugdale et al.), and heat fluxes (Edson, Friehe).

IMPACT/APPLICATIONS

The means by which we have viewed the plankton and its physical environment in this study is novel and appropriate for future investigations. The patterns we have observed for the zooplankton in Langmuir circulations have not been seen previously. If accurate, these distributions are more heterogeneous than expected and, perhaps more significantly, exhibit contagion despite there being a mixed layer. This has implications for our understanding of pattern in acoustic backscatter, processes such as growth and mortality of the plankton, and the effects of the plankton on the biogeochemistry of the upper ocean. Most importantly, biological structure exists in the presence of strong wind and surface wave forcing.

TRANSITIONS

Our profiling instruments and software have been used in an ONR-funded study of a deep aggregation of copepods in the Santa Barbara Basin (with Kenric Osgood, now at NOAA), now finished. My use of the OPC has led to its modification for internal recording and inclusion of a time-of-flight flow sensor. This modified, *in situ* OPC is now routinely deployed in the California Cooperative Fisheries Investigations (CalCOFI) to provide data on the depth distribution of the zooplankton to complement the standard, depth-integrated estimates of zooplankton abundance from bongo net deployments. This is proving to be a significant enhancement to the already-valuable CalCOFI time series. An ancillary development has been the use of the laboratory OPC for the analysis of the size distribution of historical CalCOFI samples of zooplankton (work of M.M. Mullin funded by Sea Grant).

RELATED PROJECTS

Our ONR-funded investigation of *Calanus pacificus* in the Santa Barbara Basin is now finished and the results published (Osgood and Checkley 1996. 1997). A third-year, DOD-funded SIO graduate student is developing dissertation research based, in part, on our results. In particular, she wishes to investigate the significance of diapause by *C. pacificus* off Southern California and will use, amongst other tools, the OPC and CTD profiling system developed under this grant.

Other, related projects include the investigations of (a) turbulence with Tom Osborn (Johns Hopkins), (b) pattern with Nicolas Bez (Ecole des Mines), (c) acoustic backscatter with Rob Pinkel and Jerry Smith (SIO), (d) nutrient distributions with Richard Dugdale (USC), and (e) surface heat fluxes with Carl Friehe (UC Irvine) and Jim Edson (WHOI). Not all of these collaborations are active at present but each is intended to occur in the coming year.

PUBLICATIONS

Osgood, K.E., and D.M. Checkley, Jr. 1996. Observations of a deep aggregation of *Calanus pacificus* in the Santa Barbara Basin. Limnol. & Oceanogr., 42:997-1001.

Osgood, K.E., and D.M. Checkley, Jr. 1997. Seasonal variations in a deep aggregation of *Calanus pacificus* in the Santa Barbara Basin. Mar. Ecol. Prog. Ser., 148:59-69.